# Extracting Spectral Contrast in Landsat Thematic Mapper Image Data Using Selective Principal Component Analysis

*Pat S. Chavez, Jr.*
U. S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ 86001
*Andrew Yaw Kwarteng*
Department of Geological Sciences, University of Texas, El Paso, TX 79968

ABSTRACT: A challenge encountered with Landsat Thematic Mapper (TM) data, which includes data from six reflective spectral bands, is displaying as much information as possible in a three-image set for color compositing or digital analysis. Principal component analysis (PCA) applied to the six TM bands simultaneously is often used to address this problem. However, two problems that can be encountered using the PCA method are that information of interest might be mathematically mapped to one of the unused components and that a color composite can be difficult to interpret. "Selective" PCA can be used to minimize both of these problems.

A user is often interested in information that is unique to a spectral band rather than in the spectral characteristics of the various cover types in the image. Selective PCA can be used to enhance and map the spectral differences or contrast between different spectral regions. The spectral contrast is mapped into the second component when only two bands are used as input to PCA. The results of this type of selective PCA processing are easier to visually interpret than are the results of "standard" PCA where all six bands are used as input simultaneously. The spectral contrast among several spectral regions was mapped for a northern Arizona site using Landsat TM data. Field investigations determined that most of the spectral contrast seen in this area was due to one of the following: the amount of iron and hematite in the soils and rocks, vegetation differences, standing and running water, or the presence of gypsum, which has a higher moisture retention capability than do the surrounding soils and rocks.

## INTRODUCTION

THE LANDSAT THEMATIC MAPPER (TM) imaging system collects data that have an improved spatial resolution compared to the Landsat multispectral scanner (MSS) and improved spectral resolution compared to both the Landsat MSS and Système Probatoire d'Observation de la Terre (SPOT). The improved spatial resolution is helpful when mapping detailed high-frequency information (for example, structural features). However, the improved spectral resolution is more important when mapping cover types because differences that occur throughout the spectrum are often critical in identifying and/or separating cover types.

A challenge encountered with Landsat TM data is to map as much information as possible into a reduced subset of images for digital analysis and/or color compositing (e.g., three images for compositing). Principal component analysis (PCA) is often used to help solve the dimensionality reduction problem; however, problems can be encountered with the standard PCA method. The problems include both the loss of information of interest that is mapped to components not used and difficulty in visually interpreting a color composite made from standard PCA results.

With the various spectral bands available, the user is often interested in information that is unique to each spectral band as compared to information that is common to all the bands involved. That is, what new information does each band contribute that is not contained in the others? Mapping this spectral difference or "contrast" and understanding what causes the contrast can be important in many applications.

The objectives of this paper are (1) to describe previous work showing how selective PCA can be used to minimize the problems encountered with standard PCA to reduce the dimensionality of a data set and loss of information of interest (Chavez *et al.*, 1984), and (2) show how selective PCA can be used to map the spectral contrast between different spectral bands. We define standard and selective as follows: "standard" means that *all* the available bands are used as input to PCA, while "selective" means that only a subset of these bands are used as input. Various criteria can be used to "select" the subgroup to be used as input to PCA. In the two methods used in this paper the correlation matrix is used to identify pairs of bands which either have high correlation, for dimensionality reduction, or medium to low correlation for spectral contrast mapping. Landsat TM data of northern Arizona are used to map the spectral contrast of several cover types. Note that in this paper the term "information" is used in an informal rather than formal sense. The definition used is similar to that used by Crist and Cicone (1984) which states "new information indicates the apparent presence of previously unavailable clues or insights into the characteristics of the scene being viewed."

## TEST SITE

The test site is in extreme northern Arizona, 35 km southwest of Fredonia, Arizona, on the Colorado Plateau. The Landsat-5 TM data used in the project were acquired on 9 June, 1984. Two major surface lithologic units in the area are the Permian Kaibab and Triassic Moenkopi formations. Rocks older than the Kaibab Formation are not exposed in the study area other than in the canyons, but are known from dissected canyons and drill hole data. Southwest of Hack Canyon Quaternary volcanic ash and cinders of alkalic basaltic composition dot the landscape (Best and Brimhall, 1974).

### KAIBAB FORMATION

The Kaibab Formation consists of the lower Fossil Mountain and upper Harrisburg members. The Fossil Mountain member is chiefly a light-gray, cherty, thickbedded limestone with a thickness of 64 m (Sorauf and Billingsley, in press). This unit corresponds to the betà member of the Kaibab Formation as defined by McKee (1938). In the Grand Canyon region, the Fossil Mountain member is a cliff-forming limestone overlying

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the slope-forming Toroweap Formation. The contact between the Fossil Mountain and the Harrisburg members is gradational but is usually located at the top of the uppermost thick cliff-forming limestone bed (Sorauf and Billingsley, in press).

The Harrisburg member consists of an 85- to 91-m sequence of pale-gray limestone and dolomite, siltstone, and gypsum (Sorauf and Billingsley, in press). On the Kaibab and Kanab Plateaus the predominant units are limestone and dolomite with subordinate red and gray siltsone and sandstone. On dissected surfaces or along canyon walls, the Harrisburg Member forms a slope with projecting limestone ledges. The contact with the overlying Moenkopi Formation is an easily recognized unconformity marked by a distinct color change and basal conglomerate.

### Moenkopi Formation

The Moenkopi Formation is exposed in the northwestern portion of the Hack Canyon study area. The following description of the Moenkopi Formation is compiled from McKee (1954). The Moenkopi Formation is variable across the Colorado Plateau and generally thins from west to east. It has been subdivided into six main units, which in ascending order are Timpoweap, lower red member, Virgin limestone, middle red member, Shnabkaib, and the upper red member. In southwestern and northern Arizona, the members are composed of distinct alternating continental and marine units. The units grade into each other but can be separated on the basis of topographic expression, color, and dominant lithology.

The Timpoweap consists of conglomerates, gray limestones, and variegated yellow mudstone. The lower red member is chiefly a red-brown shaly siltstone with numerous gypsum lenses and veins. The Virgin limestone consists of gray aphanitic limestone and calcareous shaly mudstone. It is a moderately resistant cliff-forming unit that stands out between the weak red-bed series. The middle red member is predominantly red-brown siltstones and mudstones, locally containing gypsum and limestone lenses towards the top. The Schnabkaib member characteristically consists of gypsum beds and lenses, olive-gray gypsiferous siltsone, and mudstone. The upper red member is lithologically similar to the lower and middle red members. However, it contains more massive siltstones and fine sandstones which weather into resistant cliffs and ledges.

## PRINCIPAL COMPONENT ANALYSIS METHODS

Principal component analysis of remotely sensed image data has been used for various mapping and information extraction purposes for the past 15 years (Taylor, 1974; Fontanel *et al.*, 1975; Blodget *et al.*, 1978; Schowengerdt, 1983). It is a mathematical transformation that generates new images, referred to as components or axes, which are linear combinations of the original images. PCA allows the user to generate a new set of rotated axes; these axes are orthogonal to each other and the new images have no mathematical correlation with one another. The largest amount of the total variance is mapped to the first component, with decreasing variance going to each of the following components. The sum of the variance in all the components is equal to the total variance present in the original input images.

One major use of PCA is to reduce the number of images or variables that are needed for analysis, that is, dimensionality reduction. For example, PCA can be applied to the six Landsat TM reflective bands and only the first three components used for color compositing, digital analysis, and/or classification. These first three components will have a large percent of the total variance present in the original six Landsat TM bands. The reduction in dimensionality is often desired because of the large volume of data that are present and the computational demands or the three band limit in color compositing. However, two problems that can be encountered with the results of standard PCA images when used in this manner are (1) information that is not mapped to the first three components can be of significant interest, depending on the degree of correlation and spectral contrast that exist among the six Landsat TM bands (Chavez *et al.*, 1984; Williams, 1983); and (2) a color composite made from three of the six components can be difficult to visually interpret (Williams, 1983).

### Dimensionality and Color Confusion Reduction

As shown in previous work, the use of selective PCA can help minimize these two problems (Chavez *et al.*, 1984). The method in which selective PCA uses only *highly correlated*, as opposed to low to medium correlated, subsets or pairs of images as input to PCA is useful for dimensionality reduction while minimizing the amount of information lost to unused components (Chavez *et al.*, 1982; Chavez *et al.*, 1984). By grouping the images in this manner, PCA will map most of the variance or information into the first component because of the high degree of correlation among the input images; the higher components will usually have mostly noise, such as striping and bit errors, because of the high correlation (Green *et al.*, 1988). The analyses of many Landsat TM images have indicated that, in general, TM bands 1, 2, and 3 (visible bands) should be used as one group, and TM bands 5 and 7 (mid-infrared bands) should be used as a second group (Chavez *et al.*, 1984). A color composite made by using the first component of each of these two groups and TM band 4 will look very similar to a color composite made from three TM bands, one from each of the spectral regions (that is, visible—TM 1, 2, or 3; near-infrared—TM 4; and mid-infrared—TM 5 or 7). The color composite results will be easier to interpret than color composites made from standard PCA images because in the selective PCA process bands which are close to each other in the spectrum are used as a subgroup; therefore, the resultant color composite will look very similar to a color composite made from TM bands. This selective PCA color composite will usually have more of the total variance than either a TM band or standard PCA composite. Most composites made using the selective PCA will have over 98 percent of the total variance that is contained in the six TM bands (Chavez *et al.*, 1984). Table 1 shows the correlation matrix for the six Landsat TM bands used for the northern Arizona site. From the table we can see that the two subgroups mentioned above are good candidates for selective PCA for this site. Using selective PCA in this manner allows for dimensionality reduction with little loss of information of interest because the components not used have mostly noise, striping, and bit errors, due to the high degree of correlation of the input images. However, the second component of TM 5 and 7 should be visually examined before discarding because these two spectral bands are not adjacent to one another in the electromagnetic spectrum, and at times will have spectral contrast of interest (Chavez *et al.*, 1984). The degree of correlation can be a guide

Table 1. Correlation Matrix for the Six Reflective Landsat TM Bands of the Northern Arizona Site. The Degree of Correlation between Pairs of Bands Is Used to Identify the Combination of Bands to Be Used as Input to Selective PCA.

| TM Band | 1 | 2 | 3 | 4 | 5 | 7 |
|---|---|---|---|---|---|---|
| 1 | 1.00 | – | – | – | – | – |
| 2 | 0.96 | 1.00 | – | – | – | – |
| 3 | 0.85 | 0.95 | 1.00 | – | – | – |
| 4 | 0.81 | 0.92 | 0.97 | 1.00 | – | – |
| 5 | 0.79 | 0.84 | 0.83 | 0.86 | 1.00 | – |
| 7 | 0.68 | 0.79 | 0.86 | 0.88 | 0.93 | 1.00 |

to how much information will be mapped to the second component, as discussed later.

### Spectral Contrast Mapping

At times, a user is more interested in information that is unique to a spectral band, rather than in the spectral characteristics of the various cover types in the image. In the discussion above one of the primary objectives was to reduce the dimensionality of the data while minimizing the amount of information that is lost. In the following, the primary objective is to map the spectral contrast between different parts of the spectrum in order to see information that is unique, rather than common, in each band. Also important is to be able to easily interpret the results. This can be accomplished by using selective PCA and interpreting the results one image at a time (i.e., in black and white). However, a major difference to its use for dimensionality reduction, as described above, is how the groups/pairs of images to be used as input to PCA are selected and which of the resultant components are used. Instead of using a group of highly correlated images (0.90 or greater) as input to PCA and using the first component, pairs of only *two* images with medium (0.70 to 0.90) to low (less than 0.70) correlation are used as input and the second component is the one of interest (highly correlated pairs can also be used and is discussed later).

By using only two images/bands as input, the information that is common to both will be mapped to the first component and information that is unique to either one of the two images will be mapped to the second component. This makes the results easier to visually interpret because only two images/spectral regions are involved at any one time and the black-and-white image can be interpreted accordingly. The first component will have the information that is common to both images (typically, topographic and albedo or reflectance information), while the second component will have the differences or contrast between the two images (for example, visible versus the near-infrared would show vegetation contrast and visible versus mid-infrared would show moisture content contrast).

## DISCUSSION AND RESULTS

In this project the primary interest was to look at the spectral contrast in Landsat TM data of the northern Arizona site. The first and second principal components of the following pairs of TM bands were generated:

1. TM 2 and 4 (visible and near-infrared)
2. TM 2 and 7 (visible and mid-infrared)
3. TM 4 and 7 (near-infrared and mid-infrared)
4. TM 1 and 2 (visible, blue and green)
5. TM 5 and 7 (mid-infrared and mid-infrared)

These pairs were selected using the correlation matrix shown in Table 1. The first three pairs were selected in order to map the spectral contrast between the three major spectral regions. They also have lower correlation than most other pairs of bands. The fourth pair was selected to map the spectral contrast of two bands which are adjacent to each other and highly correlated. The last pair is similar to the fourth, except that the bands are not adjacent to each other and their correlation is not as high. In general, the degree of correlation should be related to the amount of total spectral contrast between the two bands (that is, the higher the correlation, the more similar are the two bands and the less the contrast). By using selective PCA with only two bands as input, the second component has information that is unique to either one of the bands, while information that is common to both is mapped to the first component. This makes it easier to "see" the information that is unique or different as compared to "seeing" it in a color composite made from these two bands because the composite will also have the information that is common to both, such as topographic and albedo. In a color composite which includes these two bands, the information that is common can overshadow the information which is unique. Table 2 shows the correlation coefficients, percent of variance mapped to principal components 1 and 2 (PC1 and PC2), and the values of the eigenvectors that are used as multiplication coefficients or loadings in PCA for each pair of TM bands. Table 2 shows that the lower the correlation between the two input images, the higher the percent of variance that gets mapped to component number two, which indicates a larger amount of spectral contrast. For example, TM bands 2 and 7 have a correlation coefficient of 0.79, and 7.2 percent of the total variance is mapped to PC2; TM bands 1 and 2 have a correlation coefficient of 0.96, and only 1.8 percent of the total variance is mapped to PC2. Of course, the location of the two bands in the spectrum and their relative location to each other will affect not only the amount of correlation, and therefore spectral contrast, but also the cause of the contrast (for example, vegetation, iron, water, or moisture content differences). If the user is interested in a particular cover type he/she can use either lab and/or field spectral information, or published spectral curves, to identify the spectral regions that should be used as input.

If more than one set of spectral regions are important, PC2 of the results of several selective PCA pairs can be used for color compositing and/or digital analysis. However, the interpretation will not be as straightforward as with a single black-and-white image which shows the difference of only two spectral regions/bands. The PCA loadings in Table 2 show that the first component is approximately equal to the average of the two input bands, while the second component is approximately equal to their difference. Similar results are reported by Siegal and Gillespie (1980). However, the loadings do favor one band over the other.

Plates 1a and 1b show the study area using two color composites made with TM bands 1, 2, 3 and 3, 4, 7, respectively. The data were contrast stretched and color composited as blue, green, and red. The upper left diagonal half (northwest) is mostly in the Moenkopi Formation while the lower right diagonal half (southeast) is mostly in the Kaibab Formation. The north-south canyon at the right is Kanab Canyon which branches off from the Grand Canyon. Kanab Creek is at the bottom of the canyon and flows into the Colorado River. The east-west branch that stops at approximately the center of the image is Hack Canyon. The main areas of interest are in the marked rectangular frames. Areas A, C, E, and F contain similar information; areas B, D,

Table 2. Correlation Coefficients, Percent of Variance Mapped to PC1 and PC2, and the Loadings Used in PCA for Each Pair of TM Bands Used to Map the Spectral Contrast for the Northern Arizona Site.

| TM PAIR | CORRELATION COEFFICIENT | PC1 % VARIANCE | PC2 % VARIANCE | PC1 LOADINGS | PC2 LOADINGS |
|---|---|---|---|---|---|
| TM 2 and 4 | 0.91 | 96.9 | 3.1 | (0.56,0.83) | (0.83, −0.56) |
| TM 2 and 7 | 0.79 | 92.8 | 7.2 | (0.45,0.89) | (0.89, −0.45) |
| TM 4 and 7 | 0.88 | 94.4 | 5.6 | (0.62,0.78) | (0.78, −0.62) |
| TM 1 and 2 | 0.96 | 98.2 | 1.8 | (0.83,0.56) | (−0.56,0.83) |
| TM 5 and 7 | 0.93 | 97.2 | 2.8 | (0.85,0.53) | (−0.53,0.85) |

G, and H each have unique information of interest. These areas are used in the discussions of the spectral contrast images in the following pages.

The first spectral contrast image shown (Figure 1) is of TM bands 2 and 4, the visible (green) and the near-infrared regions of the spectrum. A major spectral contrast between these two bands should be seen in areas with vegetation and water. The spectral contrast image (PC2) shows the vegetated areas within drainage features as dark. Within window H (right side of the images) several dark spots are seen. Field investigations indicate that these represent contrast between the amount and type of vegetation cover at these locations in comparison to their surrounding areas. The dark spots are locations that are on a slight topographic high and are covered with Juniper trees and grass, as compared to only grass on the surrounding areas. Water in the river at the lower right of the image and small watering tanks throughout the image are bright. This image also shows some slight contrast that exists between these two bands for the basalts in the lower left. Major contrast is seen along the Hack Canyon area (just right of center) and for some of the siltstones within the Moenkopi formation (upper left). The contrast within areas A and B is mostly caused by the visible contrast seen between the gray siltsone and mudstone versus the red-brown shaly siltstone of the surrounding area. The color seen in the visible part of the spectrum is controlled partially by the amount of iron in the soils, which affects what is seen in the spectral contrast image between these two spectral bands.

The second spectral contrast image (Figure 2) is of TM bands 2 and 7, the visible (green) and the mid-infrared parts of the spectrum. This pair has the lowest correlation, and several areas with major spectral contrast between these two bands can be seen in the spectral contrast/PC2 image. In the lower left, area D, the dark areas correspond to chemically altered red pyroclastics (red cinders) with a high content of hematite. The red cinders are highly oxidized, have a high total iron content, and have a high response in TM band 7 as compared to the surrounding basalts (Davis *et al.*, 1987). They are not separable with the background basalts in TM band 2. Areas A, C, E, and F were visited in the field, and gypsum was present at each site. Gypsum has a higher moisture retention capability than the background basalts and soils, and most of the spectral contrast shown in these areas is probably caused by the moisture content influence on TM band 7 as compared to TM band 2. There was no rain in the area for at least a week prior to the TM overflight. Results of moisture analysis of field samples collected from areas A, B, C, E, and F are shown in Table 3. The moisture contents of samples containing gypsum are high while the nongypsum samples have low moisture contents. Notice the difference between the two gypsum samples within area A. The sample from the north part of the area has about half the moisture (8.5 percent) of the sample from the south part of the area (17.8 percent). This difference can be seen in both the color composite shown in Plate 1b and several of the black-and-white spectral contrast images, especially in the TM bands 4 and 7 image discussed below.

TABLE 3. RESULTS OF MOISTURE ANALYSIS OF FIELD SAMPLES COLLECTED WITHIN THE AREAS SHOWN IN PLATES 1A AND 1B. ALL SAMPLES WERE WEIGHED TO THE NEAREST 0.1 GRAM, PLACED IN A GLASS BEAKER, OVEN DRIED FOR TWO DAYS, AND REWEIGHED.

| Source | %H2O | Window |
|---|---|---|
| Gypsum (20%) plus siltstone soil | 8.5 | A (top) |
| Gypsum (70%) plus siltstone soil | 17.8 | A (bottom) |
| Gray siltstone and mudstone soil | 6.2 | B |
| Caliche soil | 6.5 | B |
| Red-brown shaly siltstone soil | 2.2 | B |
| Gypsum rock interlayed with silty limestone | 17.4 | C |
| Dolomite rock | 1.0 | E |
| Gypsum rock layers | 20.7 | E |
| Gypsum soil overlaying rock layers | 20.0 | E |
| Gypsum rock layers | 20.3 | F |

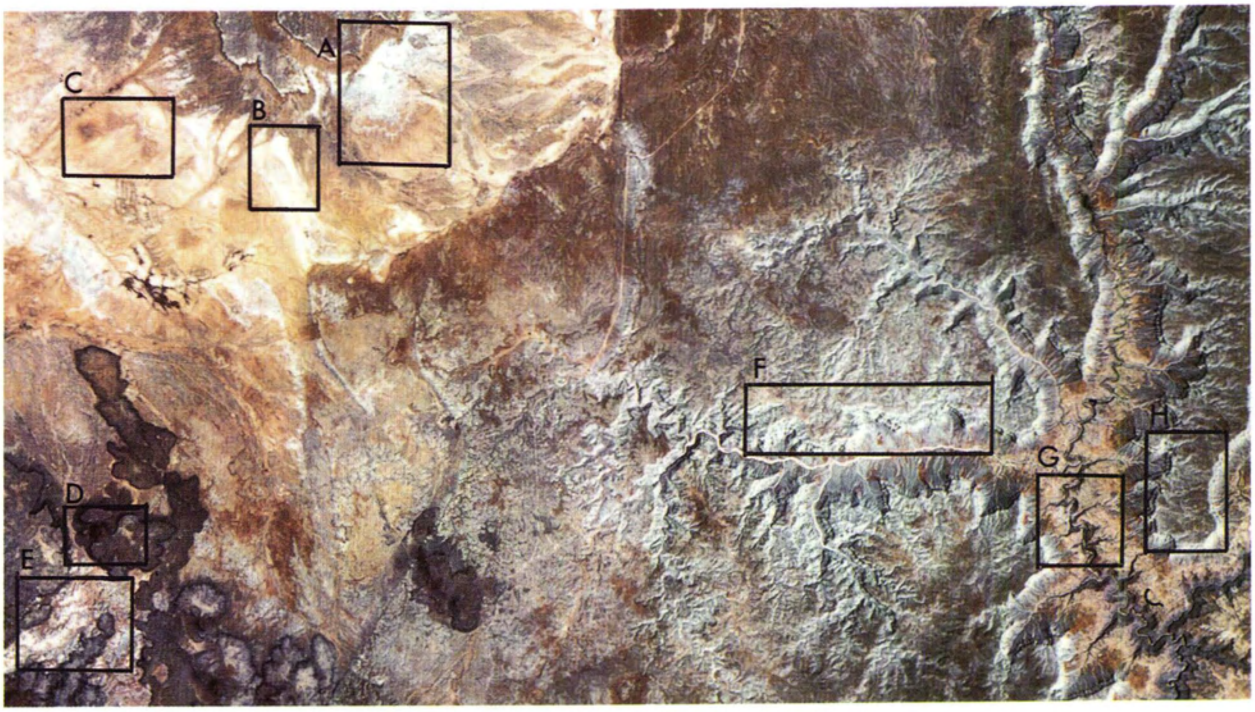
The amount of contrast caused by the gypsum varies because there is a difference in the amount of gypsum at the various locations. These differences can be seen as varying shades of blue in the TM 3, 4, and 7 color composite shown in Plate 1b. These areas do have different digital number (DN) values in the PC2 image but, because of the linear stretch applied to the data, they appear at approximately the same brightness in the black-and-white image shown in Figure 2; their DN values lie towards the higher end of the histograms. The spectral contrast of the Esplanade sandstone in the Supai formation (Billingsley *et al.*, 1983), at the bottom of Kanab Canyon (area G), is easy to see in this PC2 image. As seen in both Plates 1a and 1b, this geologic unit has high spectral contrast/differences in the various spectral regions and can be seen in several of the spectral contrast images.

The third spectral contrast image shown (Figure 3) is of TM bands 4 and 7, the near-infrared and mid-infrared spectral regions. As expected, the spectral contrast of the altered red cinders in the lower left (area D) is also visible in this PC2 image. TM band 7 displays the difference between the cinders and the background basalts, while TM band 4, like TM band 2, does not see this difference; therefore, this is identified as spectral contrast because it is unique to TM band 7. The spectral contrast of the gypsum can easily be seen. In fact, this PC2 image isolates and maps the spectral contrast of gypsum, which is related to its moisture content, better than any of the other PC2 images. These two bands do not have as much contrast as TM bands 2 and 7 along the canyon rim areas, which allows the gypsum areas to be easily identified (see area F). The Esplanade Sandstone at the bottom of Kanab Canyon does not show up as well on this image as in the TM 2 and 7 PC2 image, which implies that this unit has less spectral contrast between these two bands.

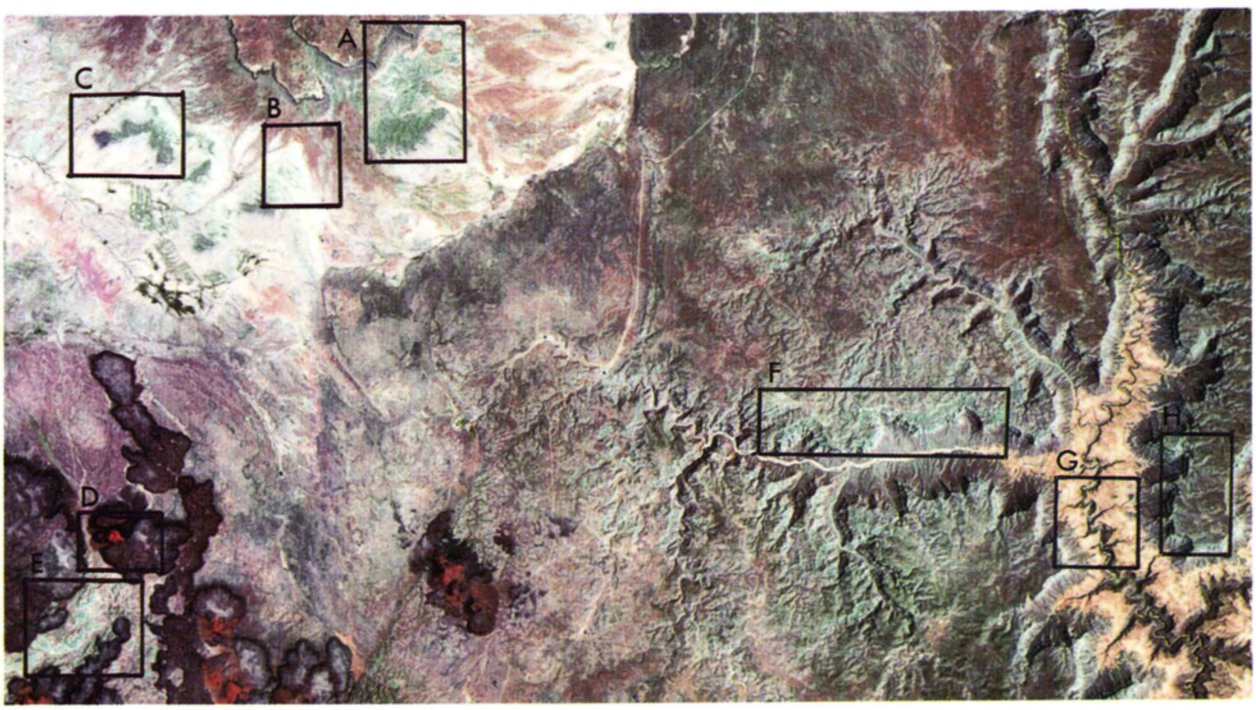
In the large bright portion in area A in the upper left of the image, two different conditions exist that affect the PC2 results of all the pair combinations. The percent of gypsum present is larger towards the south of the bright area, so combinations with TM band 7 are brighter at these locations. However, the gypsums in the northern locations are more gray than those towards the south; the locations toward the south are much closer to the same color as the background red Moenkopi soils (see Plate 1a). This color difference gives the northern locations a high spectral contrast in the visible bands. Therefore, the northern portion has high spectral contrast due to both color as well as gypsum/moisture content while the south portion is mostly gypsum/moisture related. This helps explain why there is spectral contrast in this area on all pair combinations but at different brightness levels in each PC2 image.

Image data collected in spectral bands that are next to each other are often highly correlated (Chavez *et al.*, 1984); therefore, they do not have much spectral contrast. However, to show that subtle contrast can be mapped, the PC2 images for TM bands 1 and 2 and TM bands 5 and 7 were also generated. In the PC2 image of TM bands 1 and 2 the spectral contrast seen is related mainly to the visible color differences (see Plate 1a and Figure 4). The visible color differences are mostly due to the amount of iron within the soil and rocks.

Notice that the areas A, B, and G, where sharp visible color differences can be seen in Plate 1a, are the areas with the most spectral contrast in Figure 4. The Moenkopi formation in the upper left portion of the image is also showing some slight contrast. In general, the spectral contrast in this image is low and subtle; which is expected because of the high degree of




(a)




(b)

PLATE 1. Color composite images of the study area using Landsat TM bands 1, 2, 3, and 3, 4, 7 (blue, green, red) are shown in (a) and (b), respectively. North is approximately to the top and the area covered is 45 by 25 km. The upper left diagonal half is mostly in the Moenkopi formation and the lower right diagonal half is mostly in the Kaibab Formation. Kanab Canyon is at the right extending north-south and a volcanic field can be seen in the lower left. Hack Canyon is the east-west branch that extends to about the center of the image. Rectangular windows are drawn around areas of interest. Areas A, C, E, and F contain gypsum whose high moisture contents influence the mid-infrared response; areas A, B, and G have contrast in the visible part of the spectrum; area D has chemically altered red pyroclastics/cinders which have a high content of hematite; and inside area H vegetation differences occur. These areas are discussed with the black-and-white spectral contrast images.

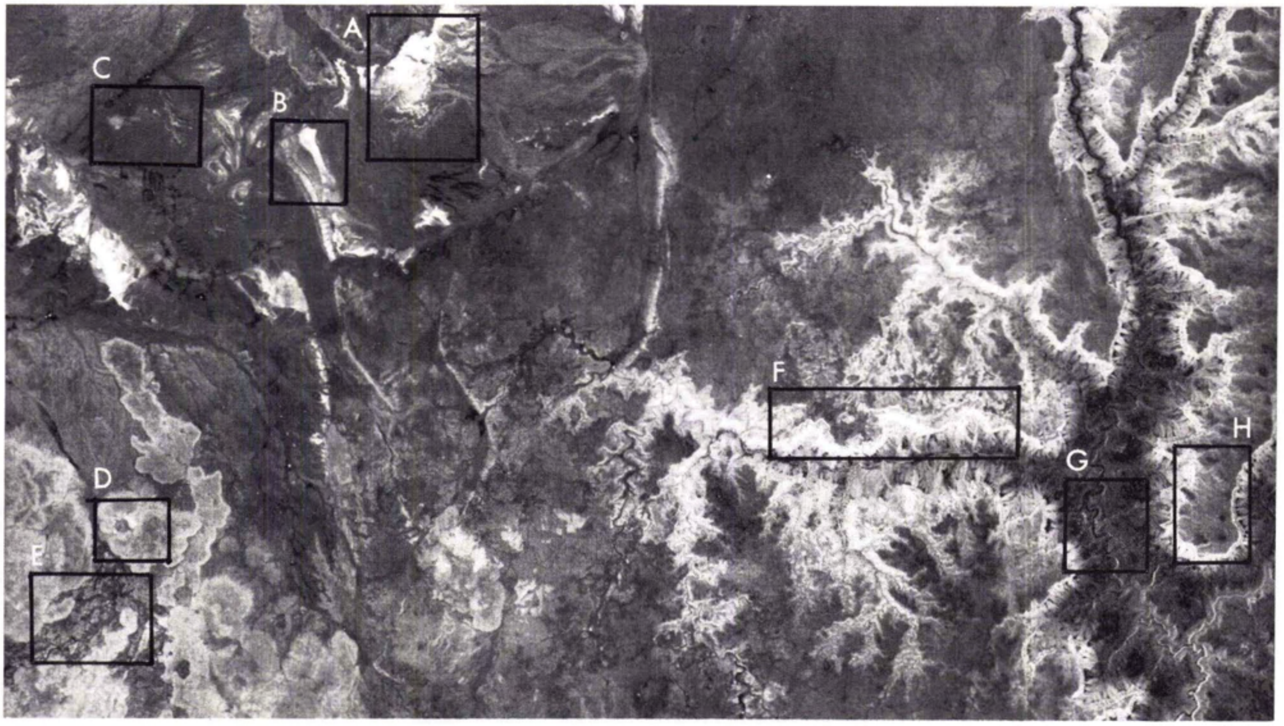



FIG. 1. Principal component number two/spectral contrast image of TM bands 2 and 4. This image shows the spectral contrast between the visible (green) and near-infrared portions of the spectrum. The high contrast that occurs inside areas A and B is due to extreme color differences that are affected by the amount of iron in the soils. The dark spots within area H are caused by vegetation differences.

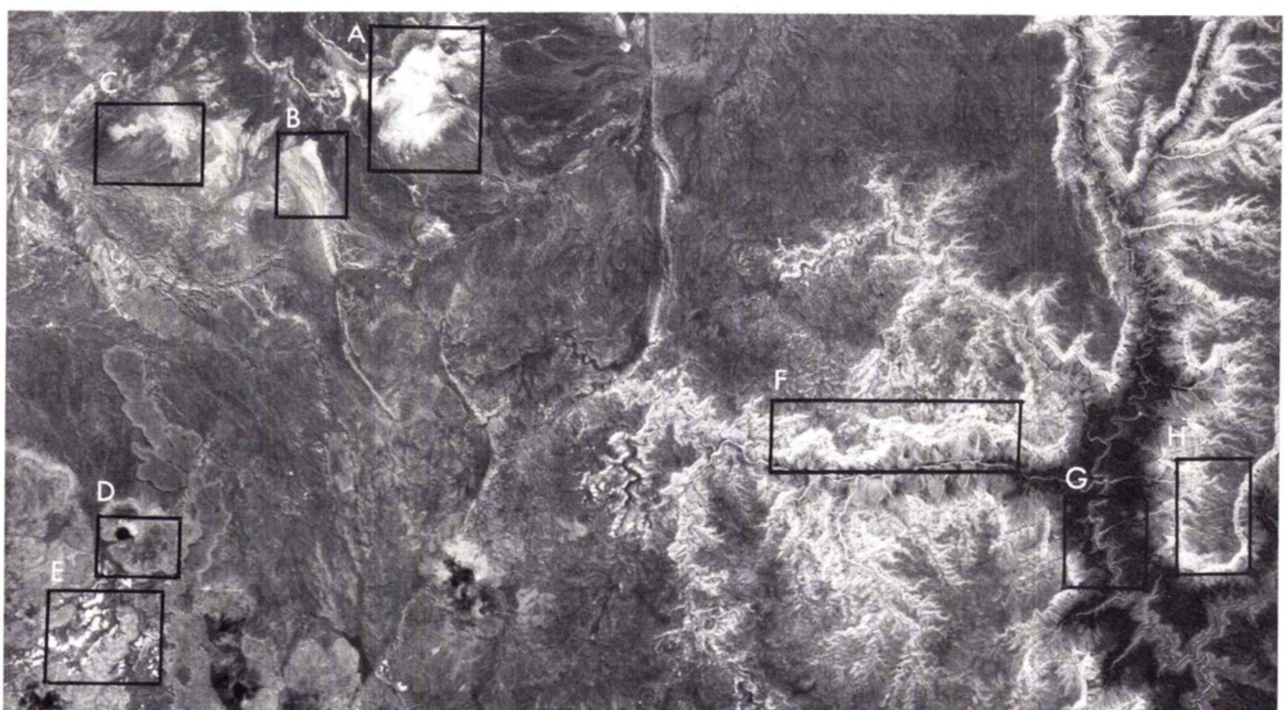



FIG. 2. Principal component number two/spectral contrast image of TM bands 2 and 7. This image shows the spectral contrast between the visible (green) and mid-infrared portions of the spectrum. The bright contrast that occurs inside areas A, C, E, and F is caused by gypsum, which has a higher moisture content than the surrounding soils and rocks. The dark contrast inside area D is caused by the altered red cinders. The dark contrast along the bottom of Kanab Canyon, including area G, is caused by the Esplanade Sandstone in the Supai Group.

correlation between TM bands 1 and 2. Of course, as stated in the previous discussion, if there is noise present in the data, it will usually be mapped to the higher order components, which in this case will be the PC2 spectral contrast image.

There is more contrast in the PC2 image of TM bands 5 and 7 than the PC2 image of TM bands 1 and 2 because of lower interband correlation (see Table 2). Even though both of these bands are in the mid-infrared, they are not adjacent to one another as are TM bands 1 and 2. In the PC2 image of TM bands 5 and 7 the altered red cinders do not show up on area D in the lower left part of the image (see Figure 5). The reason is that both TM bands 5 and 7 have a high response for the red cinders in comparison with the background basalts, therefore both can "see" this information. Because it is common to both images, and not unique to only one, this information is mapped to the PC1 and not the PC2 image. However, the gypsum is visible because there is a contrast difference bewteen TM 5 versus TM 7 (areas A, C, E, and F; that is, TM band 7 is more sensitive to moisture content than TM band 5). The areas with gypsum are showing up dark in this product because the loadings for the PC2 image are the negative of the previous PC2 images. Notice the spectral contrast that exist for the Esplanade Sandstone at the bottom of Kanab Canyon between these two TM spectral regions. Also, in the upper left portion of the image, a large area appears bright. Most of this area is covered by Moenkopi soils, and this image is showing the spectral contrast that exists for this geologic unit between TM bands 5 and 7.

It is interesting to note that there is a high degree of correlation between the PC2 image of any pair of Landsat TM bands and their ratio. For example, the PC2 image of TM bands 2 and 4 versus the ratioed image of TM bands 2 to 4 have a correlation coefficient of 0.94; the PC2 image of TM bands 5 and 7 versus the ratioed image of TM bands 2 to 7 have a correlation coefficient of 0.88. Visually the images look very similar to each other (see Figures 6a and 6b). However, the difference in the amount of contrast in areas covered with dark basalt is easily seen. The ratioed image of 2 to 4 has a higher amount of contrast in these areas and the brightness/digital numbers are larger and similar to those along the Hack canyon rim (see Figure 6a). In the ratioed image of TM bands 2 and 7 the same is generally true, except that there is also more contrast along the Hack canyon rim in the ratioed image (see Figure 6b). As mentioned earlier, the PC2 image approximately represents the difference between the regions of the spectrum represented by the two images. In comparison, the ratio of two images is directly related to the slope between the two spectral regions covered by the two images. When areas with low DN values are encountered, such as in the dark basalts and canyon rim areas in partial shadow, the ratioed value is usually affected more by a one to three DN change than is the difference.

## SUMMARY

Selective PCA can be used to both reduce the dimensionality of a data set while minimizing the loss of information and to enhance and map the spectral contrast between two different spectral regions. The selective PCA results are easier to visually interpret than are standard PCA products. The degree of correlation between two images is related to the amount of spectral contrast. The higher the correlation, the less the contrast; the lower the correlation, the more the contrast. Spectral contrast images were made using Landsat TM data of an area in northern Arizona. Areas with visible color differences caused by altered baslatic rocks with a high content of hematite, vegetation differences, and varying amounts of gypsum were enhanced in the images and identified in the field.

The spectral contrast image, which is equal to the second component of a two-image PCA, is highly correlated to the ratio image made from the same two images. The results of mapping the spectral contrast of highly correlated images, such as TM

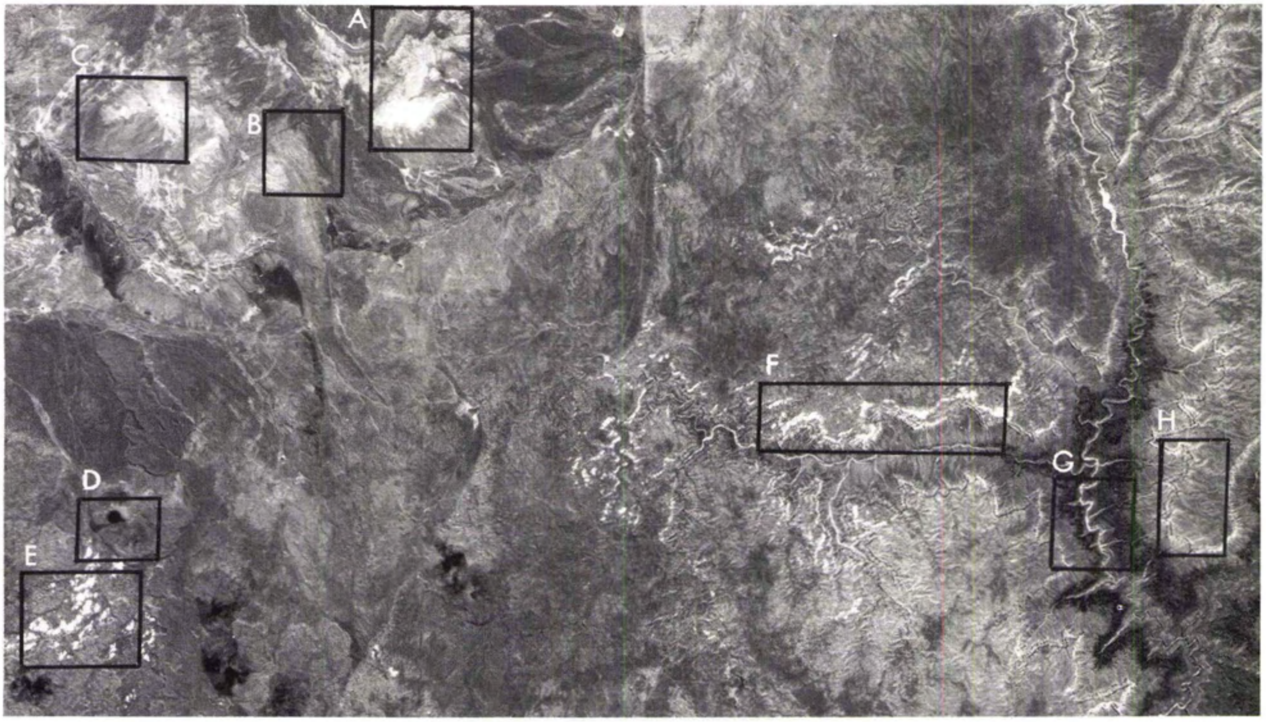



FIG. 3. Principal component number two/spectral contrast image of TM bands 4 and 7. This image shows the spectral contrast between the near-infrared and mid-infrared portions of the spectrum. This image isolates/maps the areas containing gypsum the best (areas A, C, E, and F). The chemically altered red cinders with high hematite contents are also well mapped in this image (area D).

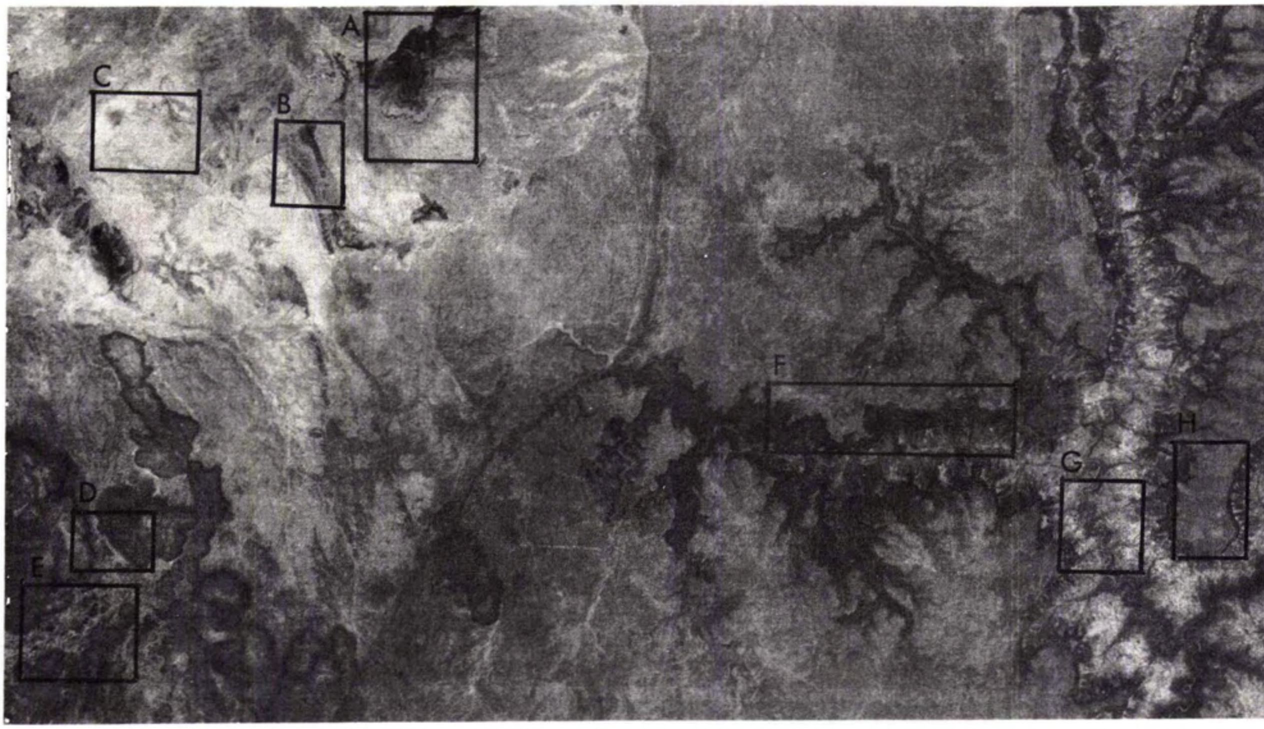



FIG. 4. Principal component number two/spectral contrast image of TM bands 1 and 2. This image shows the spectral contrast between two visible bands that are next to each other (blue and green). The spectral contrast in bands next to each other is usually subtle because of the high degree of correlation. Contrast caused by visible color differences can be seen inside areas A and G, as well as in the Moenkopi Formation in the upper left.

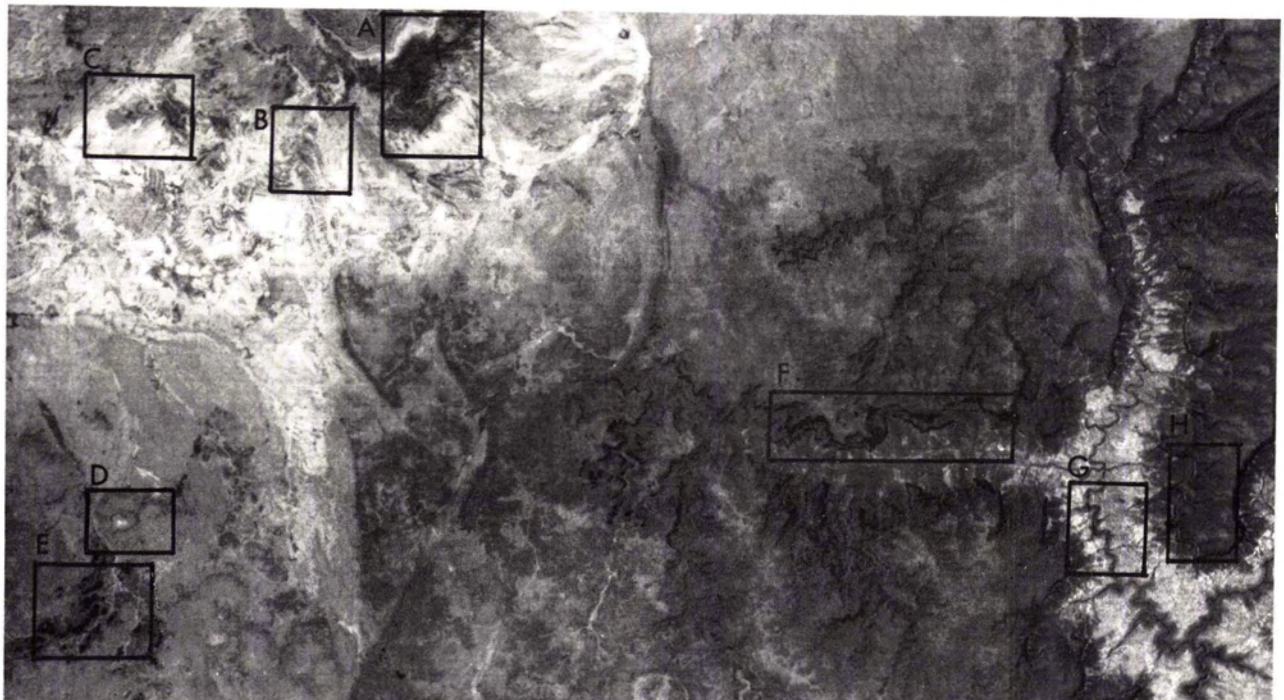
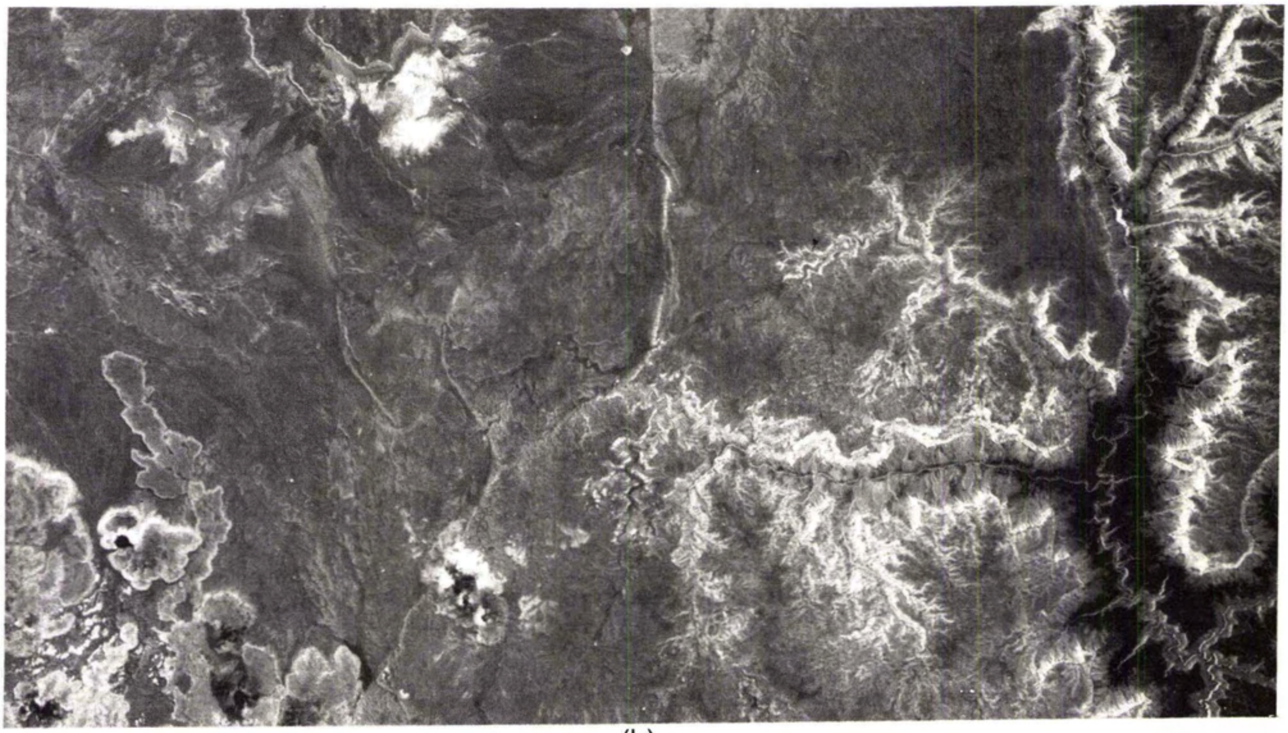



FIG. 5. Principal component number two/spectral contrast image of TM bands 5 and 7. This image shows the spectral contrast between the two Landsat mid-infrared bands. Besides showing the spectral contrast of gypsum (areas A, C, E, and F) and the Esplanade Sandstone at the bottom of Kanab Canyon, it also shows the contrast of the Moenkopi Formation (upper left area). Notice that the red cinders in area D do not show up in this image.

(a)



(b)

FIG. 6. These black-and-white prints show the ratio results of Landsat TM bands 2 to 4 (a) and 2 to 7 (b). The ratios had simple linear contrast stretches applied for visual display. These ratio images are included for comparison with their corresponding spectral contrast images shown in Figures 1 and 2, respectively. Notice the high degree of correlation between the two products.

bands 1 and 2, indicates that the method can be used to map subtle differences, which may make selective PCA as useful for temporal change detection as using the standard PCA approach of using all the bands available (Bryne *et al.*, 1980; Fung and LeDrew, 1987).

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## Current Developments in Remote Sensing Law and Practice

**American Bar Association**
**7 April 1989**
**Colorado Springs, Colorado**

The American Bar Association's Section of Natural Resources Law, through its Special Committee on Satellite Technology, will hold its second workshop on space remote sensing, *Current Developments in Remote Sensing Law and Practice,* on Friday, 7 April 1989, at the Broadmoor Hotel, Colorado Springs, Colorado, in conjunction with the US Space Foundation's Fifth National Space Symposium. The Workshop will gather speakers and participants from across the spectrum of government agencies, corporations, law firms, and non-profit organizations to examine current issues of law and policy arising from satellite-based remote sensing.

To register, for or obtain more information about the Workshop, please contact

ABA Section of Natural Resources
Attn: Ms Barbara Smith
750 N. Lake Shore Drive
Chicago, IL 60611
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